

# A few reflections on the quality of emergence in complex collective systems

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## Abstract

A number of elements towards a classification of the quality of emergence in emergent collective systems are provided. By using those elements, several classes of emergent systems are exemplified, ranging from simple aggregations of simple parts up to complex organizations of complex collective systems. In so doing, the factors likely to play a significant role in the persistence of emergence and its opposite are highlighted. From this, new elements for discussion are identified also considering elements from the philosophy of Leibniz.

## 1 Introduction

Emergence: that “magic” that produces something new and more from the interactions of a set of parts—sometimes something totally unexpected and even bewildering. Something that manifests itself with a “strength”, or an energy, or a *meaning*, that is way greater than the one exhibited by the individual parts that make the whole up.

Emergence as well as the factors responsible for its manifestation are the main characters in this work. My focus shall be quite general and will try to characterize the emergence that manifests itself from collections of simple objects up to complex organizations of complex systems. Examples shall be considered among artificial, natural, and social systems. Far from an exhaustive treatise, this may be considered as a first step towards a characterization of those factors that sustain the manifestation of emergence in complex collective systems when subjected to change. The word “change” shall assume meanings that are specific of the considered level, or “scale,” of the system at hand:

- In the case of simple objects and systems, change shall refer to, e.g., the

consequences of wear-out, defects, physical failures, or operational conditions beyond those expected or foreseen is some specification document.

- In the case of more complex collective systems, change shall include the effect of forces that disrupt or strengthen the cohesion of the social system.

I will use the term “*quality of emergence*” (QoE) to refer to the cumulative effect of the above factors and changes.

In what follows I first present, in Sect. 2, three elements useful for the characterization of the QoE in complex collective systems. Those elements are then used in Sect. 3 to define several classes of emergent systems. Some remarks on related concepts—resilience and failure semantics—are then given in Sect. 4. Preliminary lessons learned are finally summarized in Sect. 5.

## 2 Preliminaries

It is already emergence something that appears to “spring” from the simple interactions of simple interconnected objects. Let us make use of an example. If you consider a car and its parts, we see that among all of the possible combinations of the latter there are some that allow the union of the parts to become something else, something *greater*; something that makes the new element respond to a new and specific definition: in this case, the definition of car.

Here is a first, simple example of emergence: a tool that is produced by the combination of a set of components. We observe how in this case, from a systemic point of view, the compound differs only slightly from the components. Both components and compound are “simple” systems. Cogs made of cogs. Furthermore we observe how even the “glue” that holds together the components and, in fact, *realizes* the tool, is in this case very much simple: it is made of physical connections based on the material properties of the components; on their shapes; and on auxiliary components the purpose of which is to ensure the persistence of the identity of the compound; to “keep it together”, at least for a certain period of time and under certain operating conditions.

The name of this “glue” is **organization**. Emergence is therefore a property of a compound formed from components organized into a *whole*. Organization is what holds together and puts in relation the components with one another. My stance here is that these three aspects—the systemic characteristics of components, of the compound, and of the “glue”—constitute three of the key elements to characterize an emerging system and its quality.

A first aim of this paper is to lay the foundation to a future classification of “emergent systems” based on the just mentioned triplet.

Two methodological assumptions are introduced in the rest of this section.

## 2.1 Methodological assumptions and preliminary steps

Components, compound, and organization are three elements that I selected to operate a classification of emergent systems. In order to distinguish among compound and component systems, in what follows I propose to use a general systems classification such as the one introduced in [27] or [1], or their augmentations [12]. By means of one such set of classes it is possible to introduce the following definitions.

**Definition 1 (systemic quality)** *In what follows I shall refer to the systemic quality of a component or a compound as to one of the following classes:*

P: *systems only capable of passive behavior; in other words, objects.*

¬T: *systems capable of purposeful, non-teleological behavior—so-called servomechanisms.*

T: *teleological (that is, reactive) systems. These are systems that embed a feedback loop.*

T<sup>+</sup>: *more-than-teleological systems. This class includes, among others, extrapolative, learning, autonomic, adaptive, and antifragile systems [30, 7, 23].*

**Definition 2 (total order on the set of systemic qualities)** *A total order on the set of systemic classes mentioned in Definition 1 is introduced as follows:*

$$P \prec_{\sigma} \neg T \prec_{\sigma} T \prec_{\sigma} T^+.$$

For any two systems  $a$  and  $b$ , if  $a \prec_{\sigma} b$  we shall say that  $a$  is *less evolved* than  $b$ . To refer to the systemic quality of any system  $a$  we shall use notation  $\sigma(a)$ .

What just done for systems is now done for organizations.

**Definition 3 (Organizational quality)** I shall refer to the organizational quality of a set of components realizing a compound as to one of the following classes:

- + *Juxtaposition.* This is not an organization sensu proprio; rather, it is a simple grouping of elements. Emergence is in this case a consequence of the additive property of a physical quantity.
- $\Xi$  *Strictly hierarchical organizations*, characterized by top-down flow of control and bottom-up flow of feedbacks (autocracy). Several traditional human-based organizations are based on this class.
- $\Xi^+$  *Nested compositional hierarchies.* This type of organization is based on so-called “principle of increasing inclusiveness”, in which “entities at one level are composed of parts at lower levels and are themselves nested within more extensive entities” [31]. Widely adopted in nature, class  $\Xi^+$  makes a systematic use of modularity, one of the key factors leading to the emergence of complexity—what is defined in [33] as “the evolution of evolvability.”
- $\Xi^\times$  *This is the class of what I call “metarchies”:* more-than-hierarchical organizations. This includes, among others, heterarchies [29] and exception-based hierarchies [13], such as sociocracy [3] and socio-fractal organizations [6, 18, 15, 16].

As it has been done for the systemic quality, it is now possible to introduce a total order for organizations.

**Definition 4 (total order on the set of organizational qualities)** I define a total order between the classes introduced in Definition 3 as follows:

$$+ \prec_o \Xi \prec_o \Xi^+ \prec_o \Xi^\times.$$

If  $a \prec_o b$  I shall say that  $a$  is less evolved than  $b$ . In what follows I shall use symbol  $o(a)$  to refer to the organizational quality of any organization  $a$ .

To simplify the notation, when this can be done without introducing ambiguity, I will make use of symbol “ $\prec$ ” to refer to either of  $\prec_\sigma$  and  $\prec_o$ .

In what follows, I shall refer to the emergent systems as either Whole or Compound and to its elements as either Parts or Components.

### 3 Elements of a classification of emergent systems

Here I provide some elements of a classification of emergent systems.

One of the lower levels, if not the lowest, is the one of systems operating as LED lamps. Those are systems in which

- *simple components* (more precisely, systems whose behavioral class is at most  $\neg T$ )...
- ... implement a system as simple as their components (again, at most  $\neg T$ , although characterized by non-trivial emergent properties)...
- ... by means of a simple organization (“simple” meaning here “at most of class  $\Xi$ ”).

A LED lamp is in fact composed from simple...LED’s, which, however, constitute a more powerful light source. Interestingly enough, such light source is characterized by *additional* properties—properties that are not present in the constituent elements. For instance, a LED lamp is characterized by low power consumption.

But there also more “subtle” and I would say more intriguing properties that in this case characterize and *distinguish* the compound from the components—the Whole from its Parts. One such property is *graceful degradation*. While an ordinary lamp has a “binary” failure semantics (it is either “working” or not at all), a LED lamp has what I would refer to as a *fuzzy* failure semantics. In fact, there is an ample spectrum of transition states in between “working” and “not working”! I believe it is interesting to highlight that in this case the “glue”, namely the organization of the LEDs in an LED lamp, is perhaps the simplest possible. The “cohesion” that allows the Whole to emerge from its Parts is in fact based on simple physical laws. The light expressed by the Whole is produced through additive synthesis of the lights emitted by the Parts—which, among other things, makes it possible to easily vary the emerging color of the lamp [28]. By referring to the metric proposed in Sect. 1, organization is in this case of class “+”.

We can conclude that a LED lamp provides us with a first “class” of emergent systems:

$$(\neg T, \neg T, +). \quad (1)$$

Triplet (1) is representative of systems in which both compound and components are characterized by at most purposeful, non-teleological behaviors [27] and the organization is of the additive class +. As already pointed out, more than of an organization it may make more sense in this case to talk of a “grouping”—a combination of the Parts. It is worth remarking that the emergent properties gradually appear with the juxtaposition of the components, and gradually disappear with their removal or their disintegration.

**Definition 5** *Emergent systems characterized by the triplet (1) will be called in the following LED systems.*

In what follows I shall not engage in a comprehensive classification, whose attempt I aim to address in subsequent works. Aim of this paper is to pave the way for such an endeavour by defining some classes of emergent systems of particular interest—as well as to reflect about possible relationships between those classes and emergence “meta-properties” (namely, properties related to the property of emergence.)

### 3.1 Hierarchies with Components less advanced than the Compound

Here I will discuss the family of emergent systems that are characterized by the adoption of a hierarchy (thus an organization of either  $\Xi$  or  $\Xi^+$  class) and with  $o(\text{Parts}) \prec o(\text{Whole})$ . Again, this is not meant as an exhaustive treatise—rather, it is an exemplification of several of the members of a family of emergent systems.

#### 3.1.1 Organs

I shall call “organs” those emergent systems that are made of passive-behaviored components (“objects”, or “cogs”) that are assembled into a purposeful, non-teleological behaviored Whole—for example, a servomechanism. I shall use the following notation:

$$(P, \neg T, \Xi), \quad (2)$$

“Assembled” here stands for a rigid and immutable hierarchy (namely, class  $\Xi$ ).

**Definition 6** *Emergent systems characterized by the (2) triplet will be called in the following as **organs**.*

In the case of organs, the identity of the system (and thus the persistence of its “quality”) is purely related to the mechanical cohesion of the parts within the whole. In other words, there are no “centrifugal” forces [19, 20, 21] leading the individual Parts to disrupt cohesion, because the parties are mere objects. Persistence of identity and emergence is affected by wear-out, defective parts, defective assemblage, etc.

#### 3.1.2 Systems of organs

In this class of emergent systems, organs are assembled to compose an autonomous system capable of teleological / reactive behaviors [27]. In this case I shall use notation

$$(\neg T, T, \Xi). \quad (3)$$

**Definition 7** *Non-teleological Parts hierarchically united to form a teleological system, as expressed by the (3) triplet, shall be called in what follows a **system of organs**.*

The autonomic nervous system of animals is an example of a system of organs. Persistence of resilience is usually a result of wear-out, malfunctioning, defective organs, or external conditions.

### 3.1.3 Organisms

Systems of organs, organized into autonomous systems characterized by autonomy, proactivity, and other advanced capabilities (in some cases sentience, self-awareness, and antifragility [23, 12]), are called in what follows **organisms**. More formally, an organism is characterized by the following triplet:

$$(T, T^+, \Xi^+) \quad (4)$$

and is defined as follows:

**Definition 8** *Teleologically behaved Parts producing a more-than-teleologic Whole and organized as nested compositional hierarchies as expressed by the triplet (8) shall be called in what follows **organisms**.*

A fractal organization of systems of organs, as exemplified by the human body, realizes an organism.

Organisms may be characterized by a “body”—for instance, a physical, a legal, or a social “body”. Depending on the nature of its body, an organism may be more or less sensitive to disgregative forces such as wear-out, aging, external threats, parasitivism, and extreme “individualism.”

### 3.1.4 Societies

In what follows, an organization of organisms shall be called a society. More formally:

**Definition 9** *A society is an emergent system characterized by the following triplet:*

$$(T^+, T, \xi), \quad (5)$$

$\xi$  being any type of organization.

As apparent from Definition 9, societies are a peculiar case of emergent systems, in that they are an organization of highly evolved Parts that produce a Whole that is less evolved than its Parts. What is also remarkable is that said organization may vary across the whole range of organizational classes.

I shall now focus my attention on four sub-classes of societies, defined as follows.

**Definition 10 (Parasitic society)** *An organization of organisms (i.e., a society) that provides returns that are beneficial to only some of the involved organisms shall be called a **parasitic society**.*

Sentinel species [32] are an example of organisms *employed* for a purpose defined by other organisms. Canaries for instances have been used for a long time to alert miners of the presence of dangerous concentrations of toxic substances—e.g., carbon monoxide and dioxide, or methane [12]. In parasitic societies, persistence of emergence is guaranteed by the impossibility for the

Parts to leave the Whole. Other examples that come to mind are that of social systems including so-called slaves, as it was the case, e.g., in ancient Egypt, or social systems including a class deprived of most of the civil rights, as it was for instance for the *Tiers État*, the weakest of the estates in the organization of the French state before the Revolution.

**Definition 11 (Ecosystem)** *A society that sustains returns that are mutually satisfactory for the Parts and the Whole, and that is beneficial to all parties involved—without explicitly privileging some of the parties involved—shall be called in the following an **ecosystem**.*

An exemplary ecosystem is a beehive [25]. In this case *a mutualistic relationship exists between Parts and Whole*. This is similar to what happens in nature across the scales of natural systems. In fact this phenomenon takes place even between societies—the natural kingdom of animalia and that of plantae being a well-known example.

The organisms of an ecosystem are able to establish a *harmony* of sorts, recognizing the role that the Whole plays for the Parts and vice-versa. Persistence of emergence “emerges naturally” because of said sustained harmony.

An interesting paradox is that said harmony is stronger when the organisms that constitute the society have not developed a strong sense of individuality—thus their persona can more easily blend with the persona of the Whole [9]. Human societies are a classic case in which disharmony between Parts and Wholes may manifest itself. The resulting “tragedies of the common” [22] have been impacting severely on the sustainability of our species.

**Definition 12 (Factory System)** *A third sub-class of societies is a **factory system**, namely one that provides unbalanced returns that, although being mutually beneficial, are biased towards a subset of the Parts.*

The Industrial Revolution and subsequent times produced many extreme cases of factory systems—ironically rendered by Charles Chaplin in his renowned “Modern Times” as a human organism caged into a production mechanism.

Remarkable traits of a factory system are the minimal or absent identification of the components with the compound. The Parts typically do not blend into the Whole while the Whole often does not recognize or value the individuality of the Parts, which are regarded in the same way as interchangeable parts in a manufacturing system. Cohesion and persistence of emergence are a consequence of environmental conditions that motivate the parts to accept their role of components despite the unbalanced returns.

**Definition 13 (Defense System)** *A fourth sub-class of societies is a **defense system**, namely a society of organisms whose major sought after return is survivability of the Whole and the Parts in the face of an external threat.*

The external threat (the “foe”) personifies the reason for cohesion and reduces centrifugal forces despite the adoption of rigid forms of hierarchy (typically,  $\Xi$ ). Persistence of emergence is also strengthened by specific internal regulation (in the case of armed forces, this is called “military justice”).

## 4 Resilience and failure semantics

### 4.1 Resilience as a dynamic property

In Sect. 2 I briefly hinted at a crucial aspect that has not been further developed in the present article. I refer to resilience, namely a compound’s persistence of identity [11, 12]. There is clearly a strong link between QoE and resilience, as a system’s identity prescribes and details the emergence of a number of expected properties, traits, or characteristics.

It is important to realize that, as QoE, also resilience is a *dynamic* property: a compound retains its characteristics “for a certain period of time and under certain operating conditions”. Resilience is thus a trait that may appear, be sustained for a while, and then disappear. As a consequence, rather than considering QoE as an absolute property, we should consider a reference QoE and match it continuously with an actual, observed, QoE. The already mentioned example of a car applies here too: the concept of car entails a number of reference properties—for instance, the car should move as we expect it to do; should be controllable by means of an agreed upon, standard interface; and so on. When the observed properties of a car drift away from those reference properties, the car loses its identity. In other words, in order to be a car, a system should “behave” like a car. When the observed behaviors do not match anymore the expected ones, the car is no more resilient. The approach I followed in [7, 17] is to measure resilience by considering a drift from the reference quality—in fact, a distance. Such drift, or distance, is also a dynamic system—thus a property that varies in time. In the cited papers I highlighted how different resilience classes may be associated to different ways for the drift to vary in time. A more fine-grained classification of QoE should also consider the resilience class exhibit by the system under consideration.

### 4.2 Resilience as a compound’s property

A way to model a compound’s resilience is possibly given by considering the *energy* that binds together the components into the compound and allows them to fulfill the roles prescribed by the organization. Said energy is finite. When it goes below a given threshold, a component and possibly its compound lose their identity. In order to prolongue the life of the compound, certain components may be replaced—as an old tire is replaced with a new one, for instance. When such process can be done autonomously, then the system is said to self-repair.

In some cases this replacement is difficult or impossible to achieve. We can replace a “heart” though we can not replace a “brain”. In such a case, the system dis-integrates—it “dies”. A compound characterized by a certain aggregation quality breaks down into its components, thereby loosing the identity-of-the-compound. Like a castle of cards that fall down, the compound that once stood and now stands no more becomes again “simply a pack of cards”. The ancient ones reflected on this very phenomenon and associated it with *sadness*. Asclepius’s Lament in the Corpus Hermeticum [26] stands for the sorrow associated

with this loss of emergence<sup>1</sup>—especially when induced by external forces; with “divinity” leaving the living statues of Horus and “returning from Earth to Heaven” [5]. Said “divinity”, which Giordano Bruno calls “profound magic”, is indeed the miracle of the persistence of identity [2].

### 4.3 A note on failure semantics

In Sect. 3 we briefly mentioned the role of failure semantics—the way a system loses its resilience and stops manifesting its emerging properties. As we exemplified already, systems with the same purpose may fail very differently. This change of failure semantics is what we observe when moving for instance from the traditional concept of car to that of drive-by-wire car: as already mentioned, although in both cases the purpose is the same, not so are the organizations of the parts across the scales of those systems. The fact that the purpose is the same should not trick us into believing that both systems shall fail the same way. A mechanical car often exhibits graceful degradation. Moreover, if an electronic car bumps lightly into a wall, the identity of that car may have suffered in a more subtle, less evident way than the identity of a traditional car. In other words, electronic cars are inherently more “fragile” than traditional ones.

## 5 Conclusions

In this paper I provided a number of elements towards a classification of the quality of emergence in emergent collective systems. A number of classes of emergent systems has been exemplified, ranging from simple aggregations of simple parts up to complex organizations of complex collective systems. In each class we highlighted those factors that appear to play a significant role in the persistence of emergence or its opposite. A lesson learned while collecting the above results is that apart from classic causes—such as deterioration or wear-out; design faults; defective or non-optimal components, etc.—a significant role in the sustaining of emergence is *harmony* between the Parts and the Whole. Lack of said harmony translates in fact into disruptive forces that minimize identification of the Parts with the Whole and therefore tend to repel the former from the latter. My conjecture here is that indicators of disharmony may be defined by considering possible mismatches between  $\sigma(\text{Components})$  and  $\sigma(\text{Compound})$ , as well as mismatches between  $\sigma(\text{Components})$  and  $\sigma(\text{Organization})$ .

From the above reasoning, a new element to the present discussion naturally *emerges*: a fourth element to the triplet (compound, components, organization) may be *sustainability*, which I interpret here as a collective system’s propensity

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<sup>1</sup> “This All, which is a good thing, the best that can be seen in the past, the present and the future, will be in danger of perishing; men will esteem it a burden; and then they will despise and no longer cherish *this whole of the universe*, incomparable work of God, glorious construction, good creation made up of an infinite diversity of forms, instrument of the will of God who, without envy, pours forth his favour on all his work, in which is assembled in one whole, in a harmonious diversity, all that can be seen that is worthy of reverence, praise and love.” [5].

towards the realization of mutualistic relationships, strengthening identification, and other “centripetal” forces.

A final remark brings me back to my first example, when I considered a car and its parts and I mentioned that among all of the possible combinations of the parts there are some that allow the compound to become something “else”. I think it is important to remark here how emergence indicates the birth of a new concept, of a new and unique “substance” responding to a new *definition*—in Aristotelian and Leibnitian terms [10, 8, 4]. Moreover, “substance” is the materialization / implementation / *realization* of an abstract concept—what Leibniz calls a *monad*; thus, it is a “physical” rendition of a purely conceptual idea. It is again Leibniz that suggests that QoE may be better assessed by considering an intrinsic, an extrinsic, and a “social” element:

Intrinsic element: The “design choices” of which elements to combine and how.  
This, in a sense, is the “abstract code” of the system being considered.

Extrinsic element: The “implementation choices” of which “physical” parts; organs; organisms; and societies to employ in order to produce a material instance of the abstract code.

Social element: The “compossibility” (compatibility) of the material instance when integrated in a society of other substances [24]; a concept that anticipates Darwinian fitness and evolution.

A preliminary discussion of the above elements is available in the draft paper [14] and shall be further elaborated in future contributions.

## References

- [1] Kenneth Boulding. General systems theory—the skeleton of science. *Management Science*, 2(3), April 1956. 3
- [2] Giordano Bruno Nolano. *Dialoghi filosofici italiani*. Mondadori, Milano, Italy, 2000. 10
- [3] John Buck and Gerard Endenburg. The creative forces of self-organization. Technical report, Sociocratic Center, Rotterdam, The Netherlands, 2012. 4
- [4] Patryk Burek. Adoption of the classical theory of definition to ontology modeling. In Christoph Bussler and Dieter Fensel, editors, *Proc. of the 11th Int.l Conf. on Artificial Intelligence: Methodology, Systems, and Applications (AIMSA 2004)*, LNAI 3192. Springer, 2004. 11
- [5] Philip Coppens. The lament of hermes the egyptian. Available online at <http://www.philipcoppens.com/thelament.html>, 04 April 2016. 10

- [6] Vincenzo De Florio. On the constituent attributes of software and organisational resilience. *Interdisciplinary Science Reviews*, 38(2), June 2013. 4
- [7] Vincenzo De Florio. Antifragility = elasticity + resilience + machine learning. Models and algorithms for open system fidelity. *Procedia Computer Science*, 32:834–841, 2014. 1st ANTIFRAGILE workshop (ANTIFRAGILE-2015), the 5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014). 3, 9
- [8] Vincenzo De Florio. Behavior, organization, substance: Three gestalts of general systems theory. In *Proceedings of the IEEE 2014 Conference on Norbert Wiener in the 21st Century*. IEEE, June 2014. 11
- [9] Vincenzo De Florio. Quality Indicators for Collective Systems Resilience. *Emergence: Complexity & Organization*, 16(3), September 2014. 8
- [10] Vincenzo De Florio. Systems, resilience, and organization: Analogies and points of contact with hierarchy theory. *CoRR*, abs/1411.0092, 2014. 11
- [11] Vincenzo De Florio. On environments as systemic exoskeletons: crosscutting optimizers and antifragility enablers. *Journal of Reliable Intelligent Environments*, 1(2–4):61–73, 2015. 9
- [12] Vincenzo De Florio. On resilient behaviors in computational systems and environments. *Journal of Reliable Intelligent Environments*, pages 1–14, 2015. 3, 7, 9
- [13] Vincenzo De Florio. Reflections on organization, emergence, and control in sociotechnical systems. In Robert MacDougall, editor, *Communication and Control: Tools, Systems, and New Dimensions*. Lexington, 2015. 4
- [14] Vincenzo De Florio. Interpretations of the concepts of resilience and evolution in the philosophy of Leibniz. Available online at [https://www.academia.edu/24731568/Interpretations\\_of\\_the\\_concepts\\_of\\_resilience\\_and\\_evolution\\_in\\_the\\_philosophy\\_of\\_Leibniz](https://www.academia.edu/24731568/Interpretations_of_the_concepts_of_resilience_and_evolution_in_the_philosophy_of_Leibniz), April 2016. 11
- [15] Vincenzo De Florio and Arianit Pajaziti. How resilient are our societies? analyses, models, and preliminary results. In *Complex Systems (WCCS), 2015 Third World Conference on*. IEEE, 2015. 4
- [16] Vincenzo De Florio and Arianit Pajaziti. Tapping into the wells of social energy: A case study based on falls identification. In *Proceedings of the Third Conference on Complex Systems (WCCS-15)*. IEEE, 2015. 4
- [17] Vincenzo De Florio and Giuseppe Primiero. A framework for trustworthiness assessment based on fidelity in cyber and physical domains. *Procedia Computer Science*, 52:996–1003, 2015. Proc. of the 2nd Workshop on Computational Antifragility and Antifragile Engineering (ANTIFRAGILE’15),

in the framework of the 6th International Conference on Ambient Systems, Networks and Technologies (ANT-2015). 9

- [18] Vincenzo De Florio, Hong Sun, Jonas Buys, and Chris Blondia. On the impact of fractal organization on the performance of socio-technical systems. In *Proceedings of the 2013 International Workshop on Intelligent Techniques for Ubiquitous Systems (ITUS 2013)*, Vietri sul Mare, Italy, December 2013. IEEE. 4
- [19] Piero Dominici. *La comunicazione nella società ipercomplessa. Condividere la conoscenza per governare il mutamento*. FrancoAngeli, 2011. 6
- [20] Piero Dominici. Comunicazione e produzione sociale di conoscenza: nuovi scenari per le organizzazioni complesse. *Rivista Trimestrale di Scienza dell'Amministrazione*, III, 2013. 6
- [21] Piero Dominici. *Dentro la Società interconnessa. Prospettive etiche per un nuovo ecosistema della comunicazione*. FrancoAngeli, 2014. 6
- [22] Garrett Hardin. The tragedy of the commons. *Science*, 162(3859):1243–1248, December 1968. 8
- [23] Kennie H. Jones. Engineering antifragile systems: A change in design philosophy. *Procedia Computer Science*, 32:870–875, 2014. 1st ANTIFRAGILE workshop (ANTIFRAGILE-2015), the 5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014). 3, 7
- [24] G.W. Leibniz and L.H. Strickland. *The shorter Leibniz texts: a collection of new translations*. Continuum impacts. Continuum, 2006. 11
- [25] Maurice Maeterlinck. *The Life of the Bee*. Dodd, Mead and Company, NY, 1910. 8
- [26] George Robert Stow Mead. *Thrice Greatest Hermes: Studies in Hellenistic Theosophy and Gnosis, Volume II*. The Teosophical Publishing Society, London, 1906. 9
- [27] Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow. Behavior, purpose and teleology. *Philosophy of Science*, 10(1):18–24, 1943. 3, 5, 6
- [28] E. Fred Schubert. *Light-Emitting Diodes*. Cambridge University Press, Cambridge, UK, 2nd edition, 2006. 5
- [29] David C. Stark. *The Biology of Business: Decoding the Natural Laws of Enterprise* (J. H. Clippinger III, ed.), chapter Hierarchy: Distributing Authority and Organizing Diversity, pages 153–179. Jossey-Bass, 1999. 4
- [30] Nassim Nicholas Taleb. *Antifragile: Things That Gain from Disorder*. Random House Publishing Group, 2012. 3

- [31] Ilya Témkin and Niles Eldredge. Networks and hierarchies: Approaching complexity in evolutionary theory. In E. Serrelli and N. Gontier, editors, *Macroevolution: Explanation, Interpretation, Evidence*, pages 183–226. Springer International Publishing, 2015. [4](#)
- [32] W H van der Schalie, H S Gardner, J A Bantle, C T De Rosa, R A Finch, J S Reif, R H Reuter, L C Backer, J Burger, L C Folmar, and W S Stokes. Animals as sentinels of human health hazards of environmental chemicals. *Environmental Health Perspectives*, 107(4), 1999. [7](#)
- [33] Gunter P. Wagner and Lee Altenberg. Perspective: Complex adaptations and the evolution of evolvability. *Evolution*, 50(3), June 1996. [4](#)